In vitro reactivation of human immunodeficiency virus-1 upon stimulation with scrub typhus rickettsial infection.

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INTRODUCTION

Immune activation or perturbation of cytokine networks following microbial coinfections generally increases human immunodeficiency virus-1 (HIV-1) viremia. However, Watt and others have recently reported the possible HIV-1-inhibitory effects of scrub typhus, which is an acute febrile disease that is endemic in tropical Asia where HIV-1 infection is also prevalent. Their hypothesis is intriguing but also remains somewhat speculative, partly because of difficulty in conducting a prospective and well-controlled clinical study in Thailand, as well as a lack of precise laboratory data supporting their hypothesis. We investigated effects of Orientia tsutsugamushi infection on in vitro HIV-1 infection of peripheral blood mononuclear cells (PBMC).

MATERIALS AND METHODS

Cells. The PBMC were isolated from healthy volunteers who were not infected with HIV, as described previously. Resting CD4+ T cells were isolated from HIV-1-infected individuals whose plasma viral RNA was undetectable upon receiving highly active antiretroviral therapy (HAART) whose plasma viral load was undetectable. Stimulation of PBMC with O. tsutsugamushi induced production of proinflammatory cytokines and β-chemokines, and markedly down-regulated expression of CCR5. Although pretreatment with O. tsutsugamushi rendered PBMC resistant to R5 HIV-1, it otherwise enhanced HIV-1 replication. Stimulation by O. tsutsugamushi induced HIV-1 replication in PBMC from patients receiving HAART. These findings suggest that scrub typhus does not necessarily suppress HIV-1 infection and does have potential to enhance HIV-1 replication.

RESULTS

Dichotomous effects of O. tsutsugamushi on in vitro HIV-1 infection. In acute HIV-1 infection experiments, PBMC were infected with O. tsutsugamushi, and then infected with R5 HIV-1 (which uses chemokine receptor CCR5 to infect the cell), X4 HIV-1 (which uses CXCR4), or R5X4 HIV-1 (which uses both CCR5 and CXCR4). Stimulation with O. tsutsugamushi consistently enhanced infection with X4 or R5X4 HIV-1, irrespective of subtypes B or E (Figure...
However, the R5 HIV-1-inhibitory effect of *O. tsutsugamushi* was not consistent; it either suppressed (Figure 1E and F and donors 1, 3, and 5 in Table 1) or enhanced (donors 2 and 4 in Table 1) replication of R5 HIV-1. Cell viability of *O. tsutsugamushi*-stimulated cultures, as judged by trypan blue staining, was similar to that of unstimulated cultures. These results suggested that *O. tsutsugamushi* has several different activities against HIV-1 infection.

To more precisely delineate how *O. tsutsugamushi* can modulate HIV-1 infection, we performed single-round viral replication assays in which PBMC were uninfected or infected with *O. tsutsugamushi* prior to or after HIV-1 infection. In these assays, pretreatment with *O. tsutsugamushi* suppressed R5, but not X4 HIV-1 infection (Figure 2). In contrast, post-treatment enhanced HIV-1 infection, irrespective of coreceptor usage (Figure 2). Heat-inactivated *O. tsutsugamushi* had effects similar to those of live *O. tsutsugamushi* stocks (Figure 2). Thus, *O. tsutsugamushi* appeared to inhibit CCR5-mediated cellular entry of R5 HIV-1 and facilitate the post-entry viral replicative cycle. In addition, the productive replication of *O. tsutsugamushi* is not necessary for its effects.

**Down-regulation of CCR5 expression by *O. tsutsugamushi***. Since the level of CCR5 expression correlates well with infectability of cells with R5 HIV-1, we hypothesized that *O. tsutsugamushi* infection leads to down-regulation of CCR5 expression. Flow cytometry studies have clearly proven our hypothesis: *O. tsutsugamushi* infection down-regulated CCR5 expression (Figure 3 and Table 1) but had little effect on CXCR4 expression.

**Up-regulation of HIV-1 LTR activity by *O. tsutsugamushi***. Next, we investigated how *O. tsutsugamushi* infection en-

![Figure 1](https://example.com/figure1.png)

**FIGURE 1. Dichotomous effects of *Orientia tsutsugamushi* on in vitro replication of human immunodeficiency virus-1 (HIV-1).** Infection with *O. tsutsugamushi* enhanced replication of X4 HIV-1 (A, NL4-3 and B, ELI1) and R5X4 HIV-1 (C, 89.6 and D, 93JP-NH1), but suppressed replication of R5 HIV-1 (E, AD8 and F, YU-2). Peripheral blood mononuclear cells were uninfected (squares) or infected (circles) with the *O. tsutsugamushi* Karp strain for 24 hours prior to HIV-1 infection, and HIV-1 replication was monitored by reverse transcriptase (RT) assays. Similar results were obtained using the Kuroki strain of *O. tsutsugamushi*.

![Table 1](https://example.com/table1.png)

**TABLE 1. CCR5 expression and infectability by R5 human immunodeficiency virus-1 (HIV-1) of peripheral blood mononuclear cells (PBMC) stimulated with *Orientia tsutsugamushi***

<table>
<thead>
<tr>
<th>Donor</th>
<th>CCR5 expression (%)</th>
<th>R5 HIV-1 infectability (cpm/μL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unstimulated</td>
<td>Stimulated</td>
</tr>
<tr>
<td>1</td>
<td>5.1 &lt;0.5</td>
<td>2,460 480</td>
</tr>
<tr>
<td>2</td>
<td>6.8 1.1</td>
<td>1,980 4,250</td>
</tr>
<tr>
<td>3</td>
<td>2.4 &lt;0.5</td>
<td>2,690 140</td>
</tr>
<tr>
<td>4</td>
<td>0.8 &lt;0.5</td>
<td>120 710</td>
</tr>
<tr>
<td>5</td>
<td>3.6 &lt;0.5</td>
<td>2,360 220</td>
</tr>
</tbody>
</table>

*Cell surface CCR5 expression was determined by flow cytometry 24 hours after stimulation of PBMC from five donors with the *O. tsutsugamushi* Karp strain. Peak reverse transcriptase titers in infection of unstimulated or stimulated PBMC with HIV-1 AD8 are shown as R5 HIV-1 infectability. Results in donor 1 are also shown in Figures 1E and 3.*
Enhanced post-entry HIV-1 replication. In transient expression assays using PBMC, HIV-1 LTR promoter activity from pGL-HIV-1-LTR was markedly enhanced by stimulation with O. tsutsugamushi (Figure 4). Thus, increased viral replication resulted, at least in part, from up-regulation of viral transcription.

Mediation of the effects of O. tsutsugamushi infection on HIV-1 infection through soluble activity. In good agreement with previous studies demonstrating that O. tsutsugamushi infection induces production of a number of cytokines including TNF-α, interferon-γ (IFN-γ), and β-chemokines, levels of TNF-α, IFN-γ, and RANTES protein in cell-free supernatants of O. tsutsugamushi-infected PBMC were 645 pg/mL, 170 pg/mL, and 8,350 pg/mL, respectively, while uninfected cells released <15.6 pg/mL of TNF-α, <15.6 pg/mL of IFN-γ, and 120 pg/mL of RANTES protein, respectively. Although proinflammatory cytokines such as TNF-α have been shown to transactivate HIV-1 LTR activity, IFN-γ and RANTES protein have dichotomous effects on HIV-1 replication, depending upon cell types and/or virus strains. To demonstrate that soluble activity mediated by those cytokines plays a critical role in modulating HIV-1 infection of O. tsutsugamushi-infected PBMC, cell-free supernatants were collected from O. tsutsugamushi-infected PBMC. Autologous uninfected PBMC were treated with the supernatants along with minocycline (5 μg/mL) to prevent replication of O. tsutsugamushi prior to or after infection with HIV-1. Minocycline did not influence HIV-1 infection at the concentration used in this study. As shown in Figure 5, soluble factors derived from O. tsutsugamushi-infected cells had similar effects on HIV-1 infection to O. tsutsugamushi infection per se.

In vitro reactivation of HIV-1 upon stimulation with O. tsutsugamushi. Finally, we tested whether stimulation with O. tsutsugamushi can induce HIV-1 replication from PBMC derived from HIV-1-infected individuals whose plasma viral RNA was undetectable after HAART. Apheresis to obtain PBMC was performed according to protocol approved by the National Institute of Allergy and Infectious Diseases Institutional Review Board (Bethesda, MD). The CD8+ T cells and HLA-DR+ cells were depleted by Dynabeads (Dynal, Lake Success, NY) CD8 and HLA-DR, and there were less than 0.1% HLA-DR+CD4+ T cells (activated CD4+ T cells) in the remaining PBMC preparations. These cells did not release HIV-1 p24 antigen without any stimulation; however, stimulation with phytohemagglutinin plus IL-2 induced in vitro HIV-1 replication in all patients tested (Table 2). When these cells were stimulated with O. tsutsugamushi, HIV-1 replication was induced in two of the four patients tested (Table 2). Thus, O. tsutsugamushi stimulation appears to have capability of inducing HIV-1 replication in patients whose plasma viremia is undetectable.

DISCUSSION

Orientia tsutsugamushi is a gram-negative bacillus that is an obligate intracellular parasite, and is distributed in many Asian countries and Pacific islands. Since HIV-1 infection is
also endemic in some of these areas, interaction between the two microorganisms may have clinical significance. In this regard, a recent study from Thailand has reported that acute scrub typhus infection may suppress HIV-1 infection, which is in striking contrast to many other microbial coinfections that generally result in enhanced replication of HIV-1. However, difficulty in conducting a prospective and well-controlled clinical study in Thailand, as well as the lack of precise laboratory data supporting their hypothesis, has resulted in substantial controversy. Our in vitro study has suggested that *O. tsutsugamushi* infection had impacts on HIV-1 infection in several different ways, and that the net effect depends upon the balance of positive and negative factors. Difference in the net effects observed among different donors is intriguing and deserves further evaluation. Our preliminary data suggest that a number of host factors are involved in such variability (Moriuchi M, Moriuchi H, unpublished data). For example, while up-regulation of HIV-1 expression from the LTR promoter secondary to proinflammatory cytokine production would benefit HIV-1 infection, down-regulation of CCR5 expression as well as production of chemokines would inhibit HIV-1 entry. Activation of LTR by microbial stimulation has been demonstrated in a variety of other co-infections. We have previously reported similar dichotomous effects of bacterial cell wall components such as lipopolysaccharide (LPS) of gram-negative bacilli, lipoteichoic acid of gram-positive cocci, and lipoarabinomannan of mycobacteria on HIV-1 infection. Our results in the present study were not unexpected, since *O. tsutsugamushi* contains LPS in its cell wall structure, although rickettsial LPS generally has weaker endotoxin activity than that of other gram-negative bacilli. Thus, although it is still possible that in vivo infection with *O. tsutsugamushi* may have substantially distinct effects on HIV-1 infection, our in vitro study suggests that scrub typhus does not necessarily suppress HIV-1 infection and does have potential to enhance HIV-1 replication.

Interactions between HIV and other microbes do not appear to be simple. Recently, measles infection has been shown to suppress HIV viremia in patients, and we have also demonstrated that malaria parasites may suppress HIV-1 infection

![Figure 4](image_url)  
**Figure 4.** Up-regulation of human immunodeficiency virus-1 (HIV-1) long terminal repeat (LTR) activity by *Orientia tsutsugamushi*. Peripheral blood mononuclear cells were transfected with pGL-HIV-1-LTR along with pSV2CAT or pSV-Tat, and stimulated with *O. tsutsugamushi*. Luciferase activity in the transfected cell lysates was determined two days after transfection. Results (mean ± SD) of triplicate experiments are shown.

![Figure 5](image_url)  
**Figure 5.** Mediation of the effects of infection with *Orientia tsutsugamushi* on human immunodeficiency virus-1 (HIV-1) infection through soluble activity. Peripheral blood mononuclear cells (PBMC) were infected with a replication-recombinant virus pseudotyped with envelope (env) protein from R5 HIV-1 JRFL or X4 HIV-1 HXB2. The PBMC were not treated, pretreated (pre), or post-treated (post) with supernatants from autologous PBMC infected with the *O. tsutsugamushi* Karp strain, and luciferase activity in the cell lysates was determined. Fold induction indicates luciferase activity relative to that of a control (untreated) experiment. Results (mean ± SD) of triplicate experiments are shown.

### Table 2

*In vitro* reactivation of human immunodeficiency virus-1 (HIV-1) upon stimulation with *Orientia tsutsugamushi*

<table>
<thead>
<tr>
<th>Patient</th>
<th>CD4+ T cells (µL)</th>
<th>HIV-1 RNA copies (mL)</th>
<th>p24 (pg/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unstimulated</td>
</tr>
<tr>
<td>1</td>
<td>303</td>
<td>&lt;50</td>
<td>&lt;7.8</td>
</tr>
<tr>
<td>2</td>
<td>238</td>
<td>&lt;500</td>
<td>7.8</td>
</tr>
<tr>
<td>3</td>
<td>601</td>
<td>&lt;500</td>
<td>&lt;7.8</td>
</tr>
<tr>
<td>4</td>
<td>596</td>
<td>&lt;50</td>
<td>&lt;7.8</td>
</tr>
</tbody>
</table>

Peripheral blood mononuclear cells were derived from patients 1 through 4. Plasma viremia was undetectable by the Amplicor Ultrasensitive HIV-1 Monitor assay (Roche, Diagnostics Corporation, Indianapolis, IN) in patients 1 and 4 or 5. In patients 2 and 3, were either unstimulated or stimulated as indicated. Peak HIV-1 p24 titers that were obtained on day 16 are shown. PHA = phytohemagglutinin. IL-2 = interleukin-2.  
† HIV-1 replication in the PBMC of patient 3, as determined by slight increase in p24 titer on day 16, was not able to be expanded by further passages.
Further studies are required for better understanding of interaction between these microbes and HIV-1 in co-infected patients.

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REFERENCES


